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Construction of environmentally friendly fairways based on properties of Lagrangian surface transport

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We present recent developments of a technique to estimate the potential vulnerability of the nearshore in case of sea traffic accidents, based on statistical analysis of trajectories of Lagrangian particles (Soomere et al. 2010). The relevant risks for an adverse impact released in a certain location at sea are formulated in terms of the probability of hitting a coast or, alternatively, in terms of the time it takes for the pollution to reach the coast, this time frame being called as age of particle. The technique was tested for the Gulf of Finland in the Baltic Sea, using the 3D hydrodynamic model OAAS (Andrejev, Sokolov 1989, Andrejev et al. 2004) as a tool. To resolve typical mesoscale eddies in the basin, where the internal Rossby-radius is usually only 2-4 km, the horizontal resolution of the hydrodynamic model was set to 0.5 nautical miles. The model was forced with the meteorological information downscaled from the ERA-40 database using a regional atmosphere model of the Swedish Meteorological and Hydrological Institute covering the entire Baltic Sea with a horizontal resolution of about 25 km. Initial temperature of water and salinity fields as well as time-dependent open boundary conditions were taken from results of the long-term Baltic Sea circulation simulations performed with the Rossby Centre coupled ice-ocean model (RCO). In order to provide a robust statistics the OAAS model was run for 5 years (1987-1991). This period was divided into 10 days time windows. In the beginning of each window, 10 Lagrangian particles were released in each surface grid cell and being then tracked over the duration of the window.
We discuss in detail two algorithms to construct optimal fairways based on the resulting 2D distributions of the probability of coastal hit and the particle age. In elongated sea areas like the Gulf of Finland (length is approximately 400km, width is less than 145 km) these distributions contains an elongated minimum for the probability (equivalently, a maximum for the particle age) that to some extent follows the shape of the basin. These features also roughly match the position of the typical navigational routes in the Gulf of Finland where the majority of ships carrying the largest adverse impacts sail from the Baltic Proper along the gulf to large harbors in the eastern part of it. We use this match for a simple but efficient algorithm for constructing the optimum fairway leading to the large ports near Saint Petersburg. The fairway is determined as a set of points from a selected harbor entrance and going to the west direction along the least steep gradient of the probability of hitting the coast or the average age of particles. The second approach to construct the optimal fairways is based on minimization both the probability of hitting the coast and the fairway length. This method allows constructing fairways between any two selected points and it does not depend on the basin shape. The benefit from the use of the optimum fairway is estimated using a newly introduced measure based on a line integral of the probability of hitting a coast or mean age of particle.
The described methods are not invertible: a swap of the "departure" and "arrival" points usually leads to another fairway. The reason for this hysteresis is the local character of the choice of each subsequent point, with memory of the process extending back by only one grid step.
Both methods to construct optimum fairways are thoroughly tested for the Gulf of Finland, and their limitations and benefits are discussed. The presentation contains many figures and animations to explain the method used and to show position of the concrete fairways.

References

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